Measuring Collaborative Cognition

Nancy J. Cooke
Arizona State University

CKM Workshop
January 14-16, 2003

Acknowledgements

- **NMSU Faculty**: Peter Foltz
- **NMSU Post Doc:** Brian Bell
- **NMSU Graduate Students:** Janie DeJoode, Jamie Gorman, Preston Kiekel, Rebecca Keith, Melanie Martin, Harry Pedersen
- **US Positioning, LLC:** Steven Shope
- **UCF:** Eduardo Salas, Clint Bowers
- **Sponsors**: Air Force Office of Scientific Research, Office of Naval Research, NASA Ames Research Center, Army Research Laboratory

Overview

- What is Collaborative Cognition?
- A Focus on Measurement
- Assessing Collaborative Performance & Cognition
- Toward Diagnosis of Collaborative Performance
- Conclusions

What is Collaborative Cognition?

Collaborative Cognition in Practice

Experimental Context

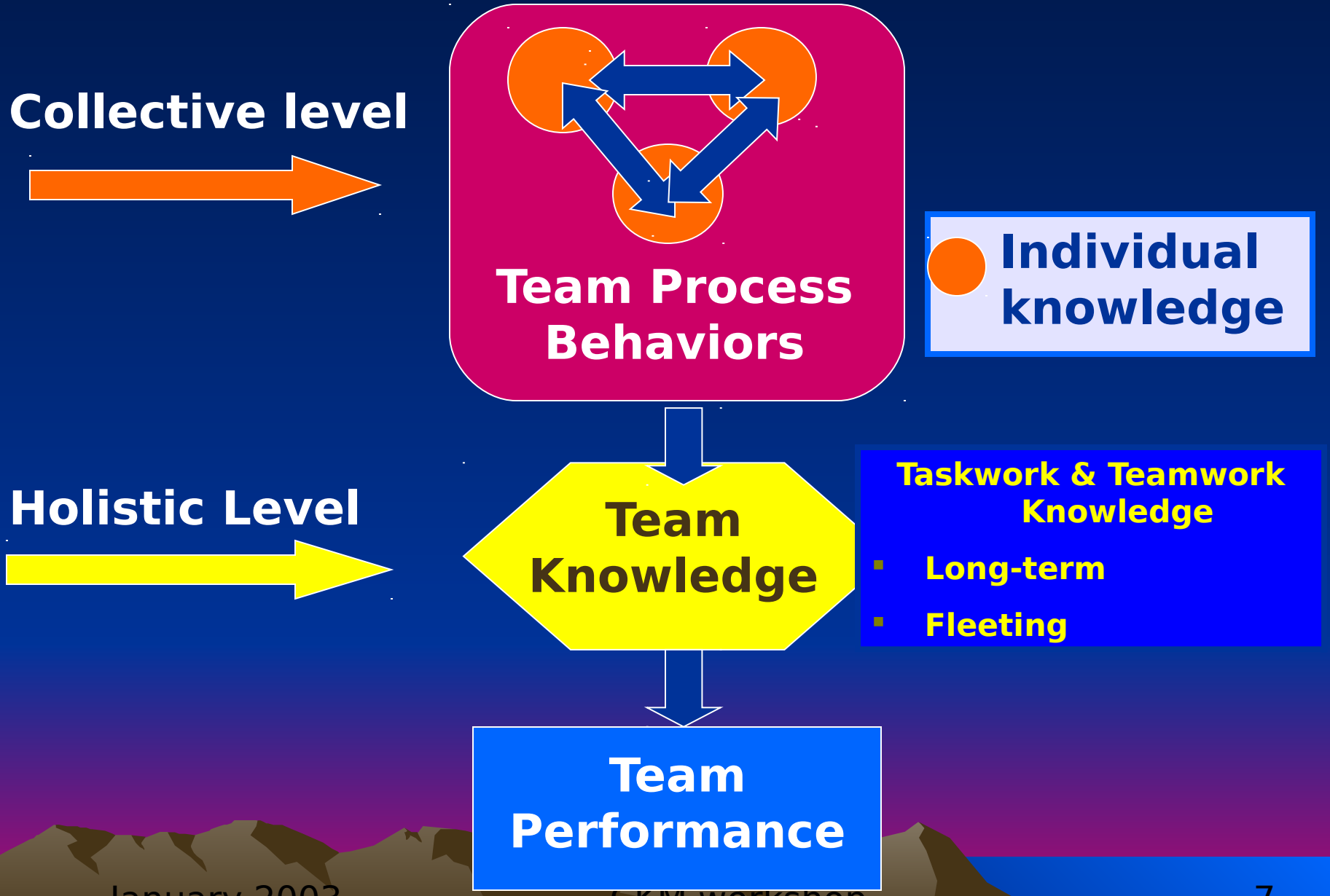
CERTT (Cognitive Engineering Research on Team Tasks) Lab

A Synthetic Task Environment for the Study of Collaborative Cognition

Five Participant Consoles

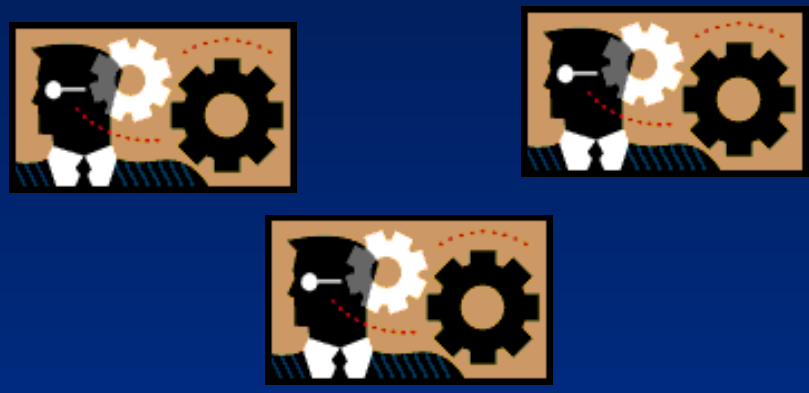
Experimenter Console

Collaborative Cognition Framework

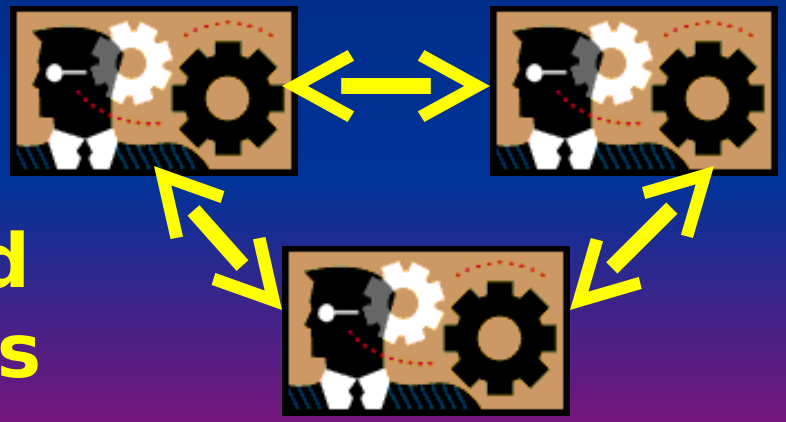


Defining Collaborative Cognition

- **It is more than the sum of the cognition of individual team members.**



- **It emerges from the interplay of the individual cognition of each team member and team process behaviors**



A Focus on Measurement

Why Measurement?

- Assessment of collaborative performance or effectiveness (criterion or dependent measures) often taken for granted.
- Outcome measures of collaborative performance do not reveal why performance is effective or ineffective.
- Process measures of collaborative behavior are often subjective and lack reliability and validity.

Why Measurement? (continued)

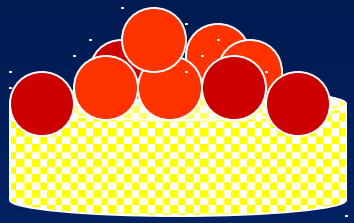
- Collaborative cognition is assumed to contribute to collaborative performance, and especially for growing number of cognitive tasks.
- Understanding the team cognition behind team performance should inform interventions (design, training, selection) to improve that performance.

Measurement Limitations

- Measures tend to assume homogeneous groups
- Measures tend to target collective level
- Aggregation methods are limited
- Measures are needed that target the more dynamic and fleeting knowledge
- Measures are needed that target different types of long-term collaborative knowledge
- A broader range of knowledge elicitation methods is needed
- A need for streamlined and embedded measures
- Newly developed measures require validation

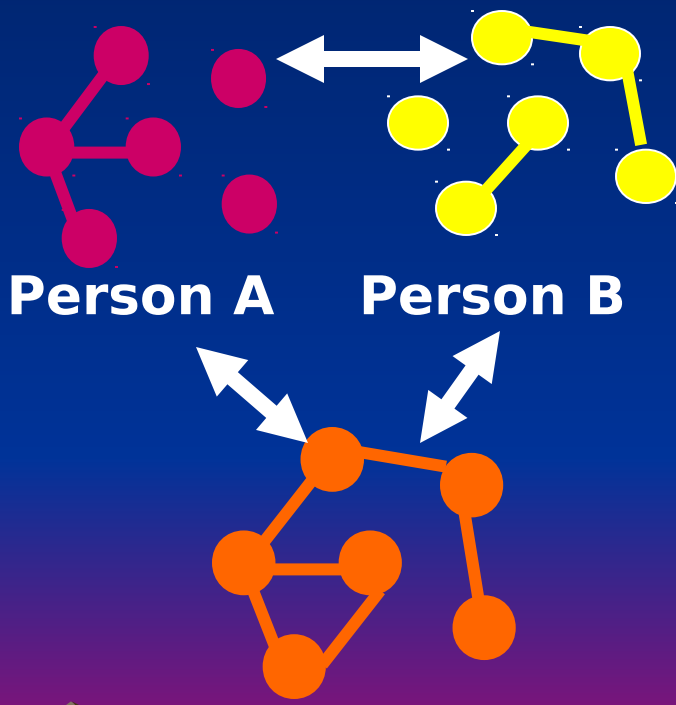
Assessing Collaborative Performance and Cognition

The "*Apples and Oranges*" Problem



Measures to assess collaborative knowledge often assume knowledge homogeneity among group members.

- Shared knowledge = similar knowledge
- Accuracy is relative to single referent

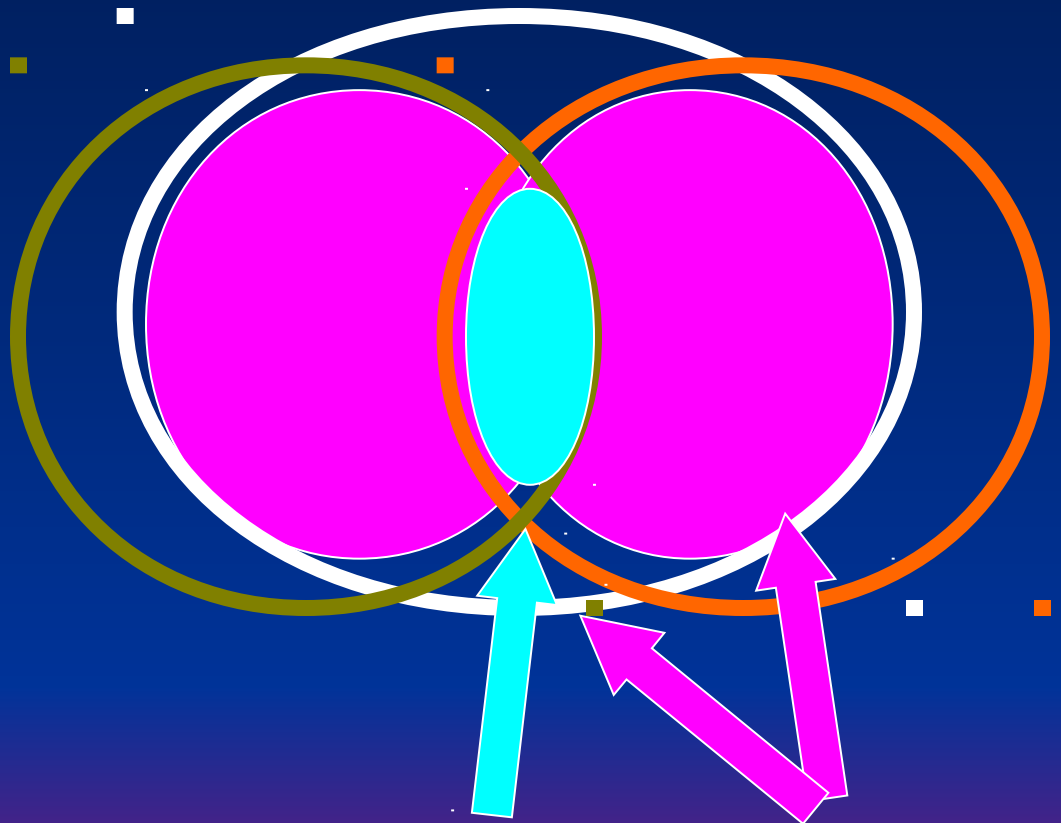


The Groups We Study Consist of "Apples and Oranges"

Airport Incident Command Center

Telemedicine

“Shared” Knowledge



Shared = Common and Complementary

An Approach to the *Apples and Oranges* Problem

Measures of team knowledge with heterogeneous accuracy metrics

Experimental Context

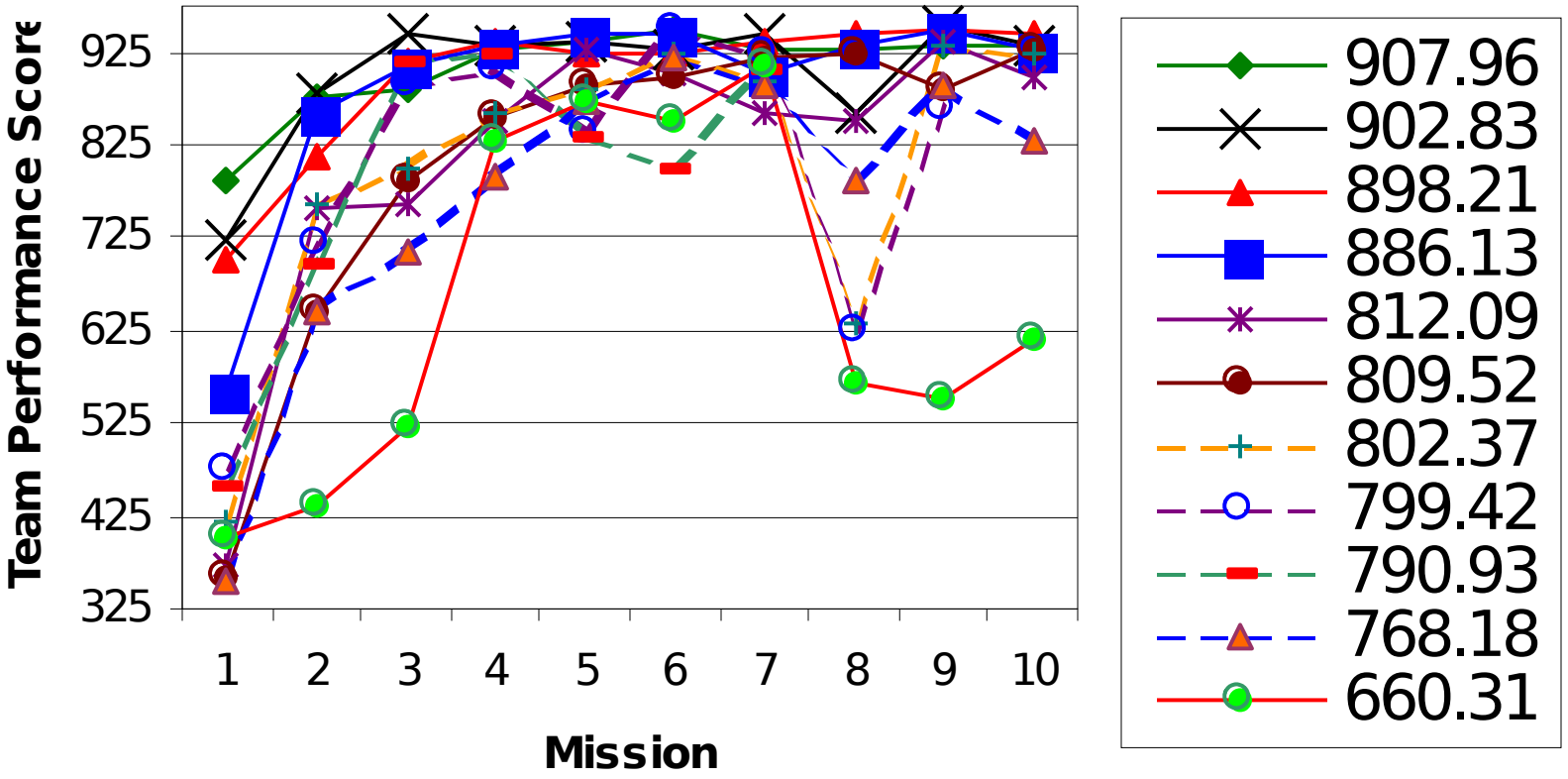
- **Five studies:** Two different 3-person tasks: UAV (Uninhabited Air Vehicle) and Navy helicopter rescue-and-relief
- **Procedure:** Training, several missions, knowledge measurement sessions
- **Manipulate:** co-located vs. distributed environments, training regime, knowledge sharing capabilities, workload

Experimental Context

MEASURES

- Team performance: composite measure
- Team process: observer ratings and critical incident checklist
- Other: Communication (flow and audio records), video, computer events, leadership, demographic questions, working memory, situation awareness
- Taskwork & Teamwork Knowledge

Scores from completed missions for all teams



Long-term Taskwork Knowledge

- **Factual Tests**

  The camera settings are determined by a) altitude, b) airspeed, c) light conditions, d) all of the above.

- **Psychological scaling**

  How related is *airspeed* to *restricted operating zone*?

Long-term Teamwork Knowledge

Given a specific task scenario, who passes what information to whom?

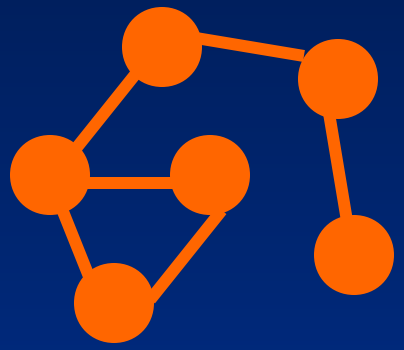
Teamwork Checklist

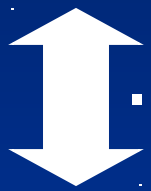
___AVO gives airspeed info to PLO
___DEMPC gives waypoint restrictions to AVO
___PLO gives current position to AVO

AVO= Air Vehicle Operator
PLO = Payload Operator
DEMPC = Navigator

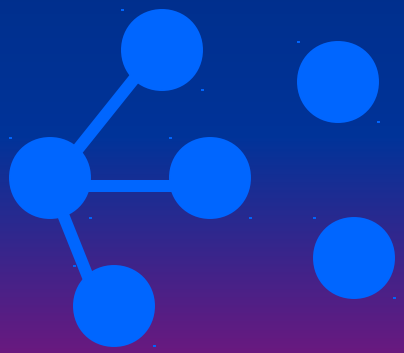
Traditional Accuracy Metrics

Team Referent



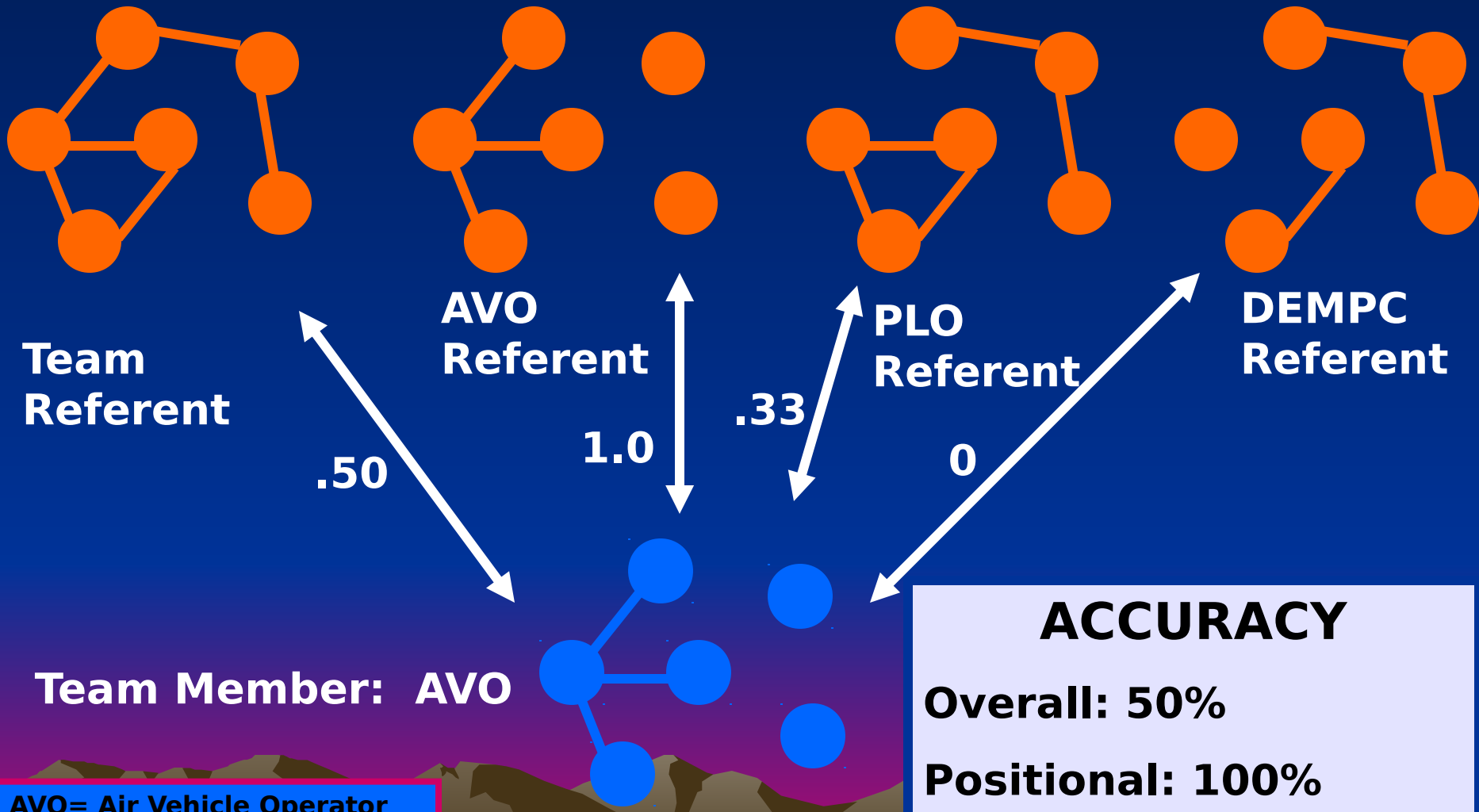


Team Member:
Air Vehicle Operator



50% ACCURACY

Heterogeneous Accuracy Metrics



ACCURACY

Overall: 50%

Positional: 100%

Interpositional: 17%

AVO= Air Vehicle Operator
PLO = Payload Operator
DEMPC = Navigator

Results Across Studies

- Taskwork knowledge is predictive of team performance

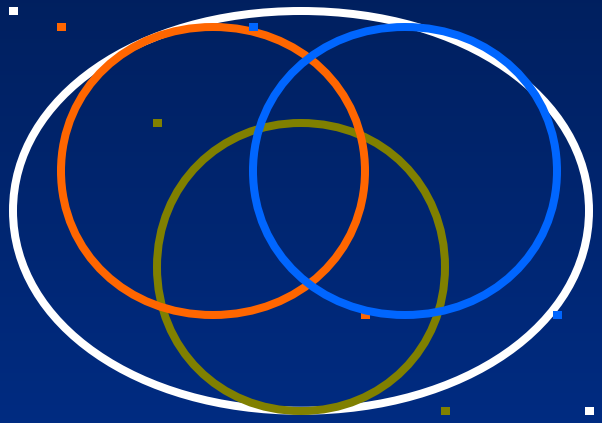
  But...
- True for psychological scaling, not factual tests
- Timing of knowledge test is critical

Knowledge Profiles of Two Tasks

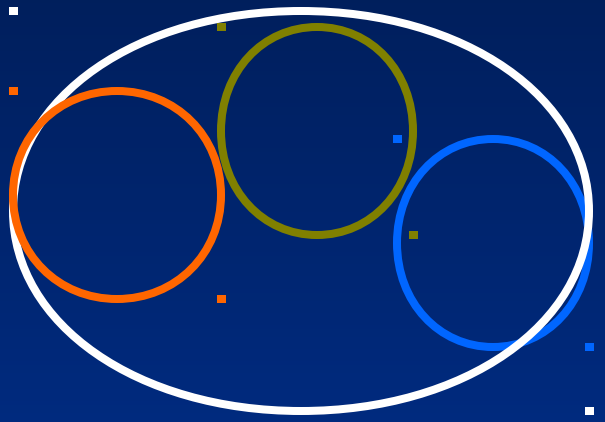
Knowledge profile characterizing effective teams depends on task (UAV vs. Navy)

	Knowledge Profile	
Knowledge metric	**Common (UAV)**	**Distributed (Navy helicopter)**
Overall accuracy	+	0
Intrateam similarity	+	0
Positional accuracy	+	+
Interposit. accuracy	+	0

Knowledge Profiles of Two Tasks



Common



Complementary

UAV Task
Command-and-Control
Interdependent
Knowledge sharing

Navy Helicopter Task
Planning and Execution
Less interdependent
Face-to-Face

A Cross-Training Study in Retrospect

- Examined effects cross-training vs. other training regimes on collaborative performance and cognition
- Unlike previous studies, cross-training had no performance benefit
- Cross-training, did increase interpositional taskwork and teamwork knowledge
- Perhaps knowledge profile for that task (specialization) was at odds with cross-training
- Demonstrates benefits of assessing collaborative cognition

However…

The descriptive information associated with cognitive assessment is not sufficiently diagnostic

Symptoms vs. Diagnoses?

- Expert chess players can remember many more meaningful chess positions than chess novices
- Experienced fighter pilots and undergraduate pilot trainees organize flight maneuver concepts differently
- Good UAV teams have interpositional knowledge
- Effective teams communicate less than ineffective ones

Toward Diagnosis of Collaborative Performance

To Move From Assessment to Diagnosis ….

Need to connect clusters of symptoms to diagnosis of team dysfunction or excellence

For example…

- Inefficient communication and low teamwork knowledge → poor team situation awareness
- Poor positional taskwork knowledge and coordination failures → faulty mental model

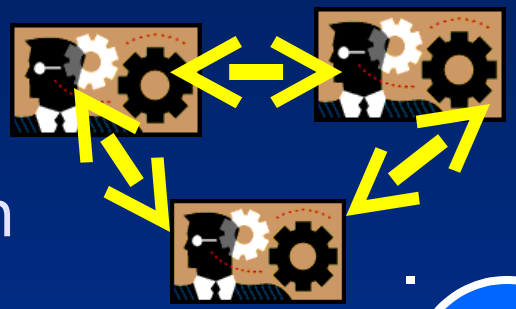
To Move From Assessment to Diagnosis ....

Also, in operational environments diagnosis is valuable to the extent that it is...

- **Conducted in real time with task performance (i.e., task-embedded, automated measures)**
- **Or better yet ...prior to task performance (based on performance precursors)**
  - Leading indicator
  - Resident pathogens
  - Non-routine events

Communication as a Window to Collaborative Cognition

- Observable; Think aloud “in the wild”
- Reflects collaborative cognition at the holistic level; is collaborative cognition
- Embedded in the task
- But…labor intensive transcription, coding, and interpretation
- Exploit its richness by automating analyses



Our Approach to Communication Analysis

- Communication Flow Analysis
- Content Analysis Using Latent Semantic Analysis

Analyzing Flow: CERTT Lab ComLog Data

Team members use push-to-talk intercom buttons to communicate. At regular intervals speaker and listener identities are logged

Analyzing Flow: ProNet--Procedural Networks

- Nodes define events that occur in a sequence
- An Example from UAV study: 6 nodes: Abeg, Aend, Pbeg, Pend, Dbeg, Dend
- ProNet: Find representative event sequences

Quantitative: Chain lengths-->Performance

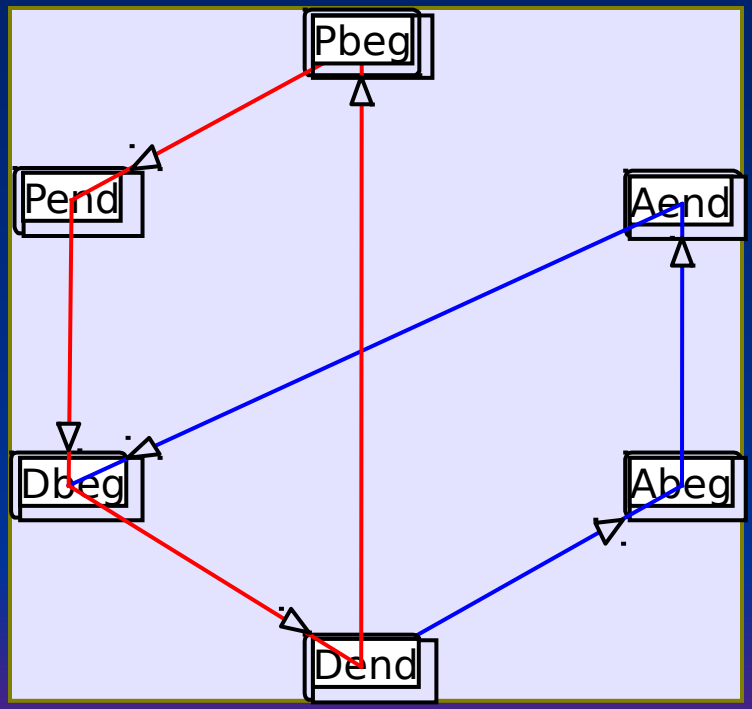
Mission 2: $R^2 = .509$, $F(2, 8) = 4.144$, $p = .058$

Mission 3: $R^2 = .275$, $F(1, 9) = 3.415$, $p = .098$

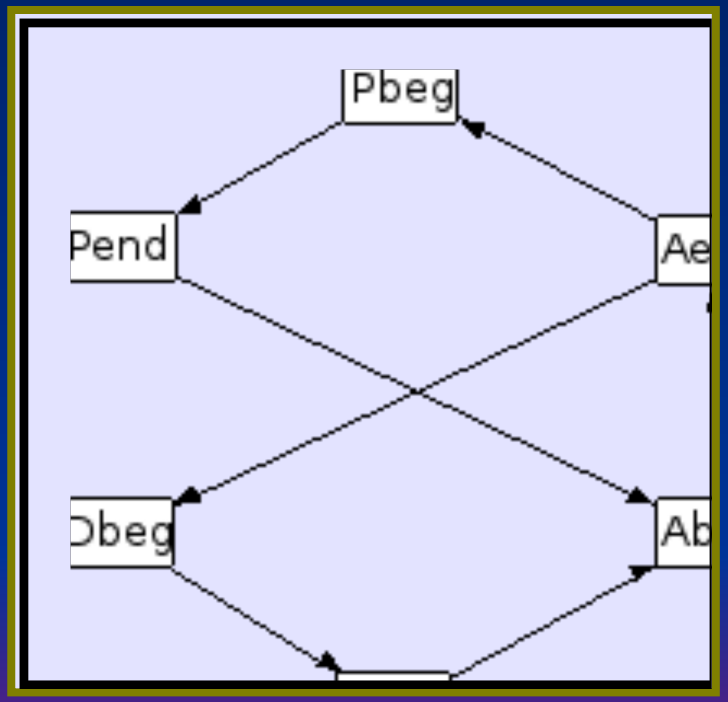
Mission 5: $R^2 = .628$, $F(2, 8) = 5.074$, $p = .051$

Analyzing Flow: ProNet--Procedural Networks

Qualitative: Communication patterns predictive of performance



Team 2 before PLO-DEMPC's fight



Team 2 after PLO-DEMPC's fight

AVO= Air Vehicle Operator
PLO = Payload Operator
DEMPC = Navigator

Analyzing Flow: Other Approaches

- Measure of speaker dominance
- Deviations from ideal flow
- Clustering model-based patterns

Content Analysis with Latent Semantic Analysis (LSA)

Landauer, Foltz, & Laham, 1998

- A tool for measuring cognitive artifacts based on semantic information.
- Provides measures of the semantic relatedness, quality, and quantity of information contained in discourse.
- Automatic and fast.
- We can derive the meaning of words through analyses of large corpora.

Content Analysis with Latent Semantic Analysis (LSA) (continued)

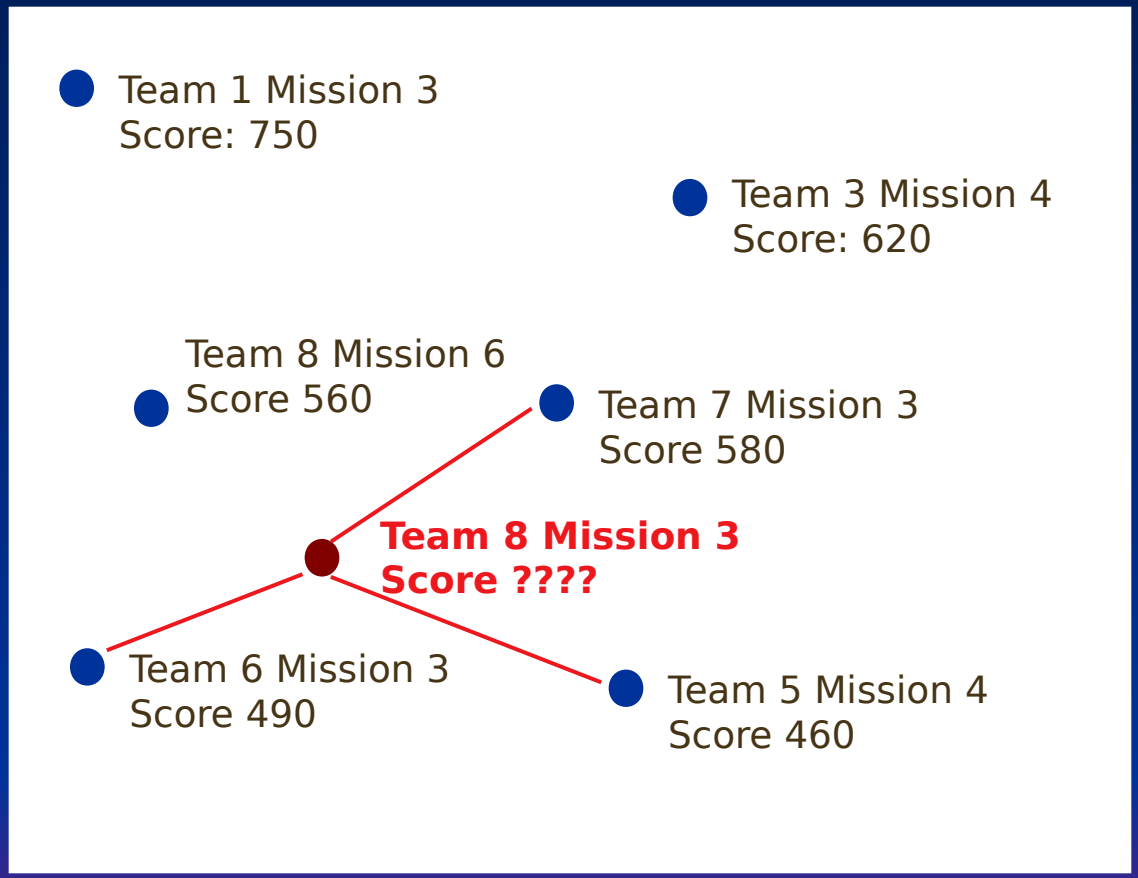
- Large constraint satisfaction problem of estimating the meaning of many passages based on their contained words (like factor analysis)
- Method represents units of text (words, sentences, discourse, essays) as vectors in a high dimensional semantic space based on correlations of usage across text contexts
- Compute degree of semantic similarity between any two units of text

Content Analysis with Latent Semantic Analysis (LSA)

An Example from UAV Study 1

- 67 Transcripts from missions 1-7
  - XML tagged with speaker and listener information
  - ~2700 minutes of spoken dialogue
  - 20,545 separate utterances (turns)
  - 232,000 words (660 k bytes of text)
- Semantic Space: 22,802 documents
  - Utterances from dialogues
  - Training material
  - Interviews with domain experts
- Derived several statistical measures of the quality of each transcript

Content Analysis with Latent Semantic Analysis (LSA)



LSA-based communication score predicts performance (r =.79).

Other Significant Variables

- Variance of scores of similar dialogues r=-.58
- Vector length, r=-.35
- Number of words, r=-.34
- Zipf R^2, r=-.47
- Percent non-function words, r=.34
- ....
- Five factor RMMR model: r=.76

Conclusion: We can accurately predict team performance from dialogues as a whole.

Analyzing Content: Other Approaches

- Automatic transcript coding
- Coherence in team dialogue
- Measures of individual contributions

Implications of Communication Work

- Collaborative cognition is revealed through discourse
- Measurement of the team as a whole, as well as individuals
- Techniques move toward automated analyses of the content of team dialogues
- Avoids tedious hand coding, keeps high reliability
- Automation will allow for task-embedded measures that assess and diagnose in real-time

Conclusions

Summary

- Understanding collaborative cognition is critical for diagnosis of team dysfunction or excellence and later intervention
- Assessment is only a first step
- Diagnostic information is needed
- In operational environments diagnosis needs to be task-embedded, automatic, and forward-looking

Implications & Applications

- Suggestions for aiding collaborative cognition through training or technology.
- Selecting/composing teams for optimal collaboration
- On-line monitoring of collaborative cognition in high-risk environments

Questions or Comments?

Contact
Nancy J. Cooke
Arizona State University

ncooke@asu.edu
http://psych.nmsu.edu/CERTT/